Realization of Current-mode Quadrature Oscillator Based on Third Order Technique

Danupat Duangmalai[1], and Winai Jaikla[2]
[1] Department of Electronics, Faculty of Nakhonphanom Technical College, Nakhonphanom University, Nakhonphanom, THAILAND
Email: kongnkp@hotmail.com
[2] Department of Electronic Technology, Faculty of Industrial Technology, Suan Sunandha Rajabhat University Bangkok, THAILAND
Email: winai.ja@hotmail.com

***Abstract*— This article presents a 3rd current-mode quadrature oscillator using current controlled current conveyor transconductance amplifier (CCCCTA) and operational transconductance amplifier (OTA) as active element as active elements. The proposed circuit is realized from a non-inverting lossless integrator and an inverting second order low-pass filter. The oscillation condition and oscillation frequency can be electronically/orthogonally controlled via input bias currents. The circuit description is very simple, consisting of merely 1 CCCCTA, 1 OTA and 2 grounded capacitors. Using only grounded elements, the proposed circuit is then suitable for IC architecture. The PSPICE simulation results are depicted, and the given results agree well with the theoretical anticipation. The power consumption is approximately 5.12mW at ±2V supply voltages.**

***Index Terms*— oscillator; current-mode; CCCCTA, OTA**

I. Introduction

It is well know that quadrature oscillators (QOs) are important blocks for various communication applications, wherein there is a requirement of multiple sinusoids which are 90æ% phase shifted, e.g. in quadrature mixers and single-sideband modulators [1]. Recently, current-mode circuits have been receiving considerable attention of due to their potential advantages such as inherently wide bandwidth, higher slew-rate, greater linearity, wider dynamic range, simple circuitry and low power consumption [2]. In 2005, a new active building block, namely current conveyor transconductance amplifier (CCTA) is a reported active component, especially suitable for a class of analog signal processing [3]. The fact that the device can operate in both current and voltage-modes provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth and simple implementation [3]. However, the CCTA can not control the parasitic resistance at X (R_x) port so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area, high power consumption and without electronic controllability. On the other hand, the introduced current-controlled current conveyor transconductand amplifier (CCCCTA) [4] has the advantage of electronic adjustability over the CCTA. A lot of attention has thus been given to oscillators utilizing the different high-performance active building blocks, such as, OTAs [10, 11], current conveyors [8], Four-Terminal Floating Nullors (FTFN) [5-6], current follower [12-13], current controlled current differencing buffered amplifiers (CCCDBAs) [15], current controlled current differencing transconductance amplifiers (CCCDTAs) [16-17], fully-differential second-generation current conveyor (FDCCII) [18], and differencing voltage current conveyor (DVCCs) [14], have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the passive elements, especially external resistors [5-6, 8, 14].
- Lack of electronic adjustability [5-6, 8, 12-13, 14].
- Output impedances are not high [5-6, 8, 12-18].
- Use of a floating capacitor, which is not convenient to further fabricate in IC [14].
- The oscillation conditions (CO) and oscillation frequencies (OF) cannot be independently controllable [10, 12-13].

The authors in this paper propose a novel current-mode quadrature oscillator using CCCCTA and OTA that overcomes all the aforementioned drawbacks. The proposed circuit provides the following advantageous features:

- Availability of quadrature explicit-current-outputs (ECOs) from high-output impedance terminals. The ECOs can also be flown into external loads to give quadrature voltage outputs. ECOs also facilitate cascading with other current-mode circuits without requiring the use of external current-followers.
- The proposed circuit employs only grounded capacitors and which is advantageous from the point of view of integrated circuit implementation as grounded capacitor circuits can compensate for the stray capacitances at their nodes.
- The circuit is completely "resistor-less", i.e. no external resistors are employed.

The circuit is governed by independent oscillation conditions and oscillation frequencies tuning laws. Thus, the circuit can be used as electronically-controlled variable frequency oscillator.

II. Circuit Theory

A. Basic Concept of CCCCTA

Since the proposed circuit is based on CCCCTA, a brief

review of CCCCTA is given in this section. The characteristics of the ideal CCCCTA are represented by the following hybrid matrix:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}, \tag{1}$$

where $$R_x = \frac{V_T}{2I_{B1}}, \tag{2}$$

and $$g_m = \frac{I_{B2}}{2V_T}. \tag{3}$$

g_m is the transconductance of the CCCCTA, V_T is the thermal voltage. I_{B1} and I_{B2} are the bias current used to control the parasitic resistance and transconductance, respectively. The symbol and the equivalent circuit of the CCCCTA are illustrated in Figs. 1(a) and (b), respectively. In general, CCCCTA can contain an arbitrary number of z and o terminals, providing currents I_z and I_o of both directions.

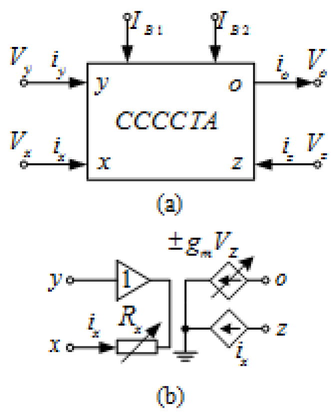

Figure 1. CCCCTA (a) Symbol (b) Equivalent circuit

B. Basic Concept of OTA

An ideal operational transconductance amplifier (OTA) has infinite input and output impedances. The output current of an OTA is given by

$$I_o = g_{mO}(V_+ - V_-). \tag{4}$$

For a bipolar OTA, the transconductance is equal to Eq. (3). The symbol and the equivalent circuit of the OTA are illustrated in Fig. 2(a) and (b), respectively.

C. General Structure of 3rd Oscillator

It has been proved that the third order oscillator provides good characteristic with lower distortion than second order oscillator [19]. So the realization of the proposed circuit is designed by using this technique. It is implemented by cascading an inverting second order low-pass filter and the lossless integrator as systematically shown in Fig. 3. From block diagram in Fig. 3, we will receive the characteristic equation as

$$s^3 + bs^2 + as + ck = 0. \tag{5}$$

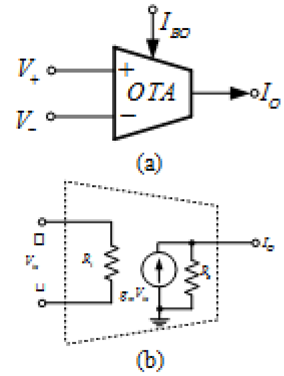

Figure 2. OTA (a) Symbol (b) Equivalent circuit

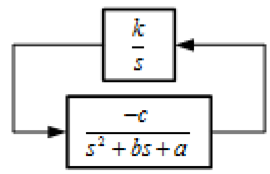

Figure 3. Implementation block diagram for the 3rd oscillator

From Eq. (5), the oscillation condition (OC) and oscillation frequency (ω_{osc}) can be written as

$$OC: ab = ck, \tag{6}$$

and $$\omega_{osc} = \sqrt{a}. \tag{7}$$

From Eqs. (6) and (7), if $a = c$, the oscillation condition and oscillation frequency can be adjusted independently, which are the oscillation condition can be controlled by k and b, while the oscillation frequency can be tuned by a.

D. Proposed 3rd Current-mode Quadrature Oscillator

As mentioned in last section, the proposed oscillator is based on the inverting second order low-pass filter and the lossless integrator. In this section, these circuits will be described. The inverting second order low-pass filter based on CCCCTA is shown in Fig. 4(a). The current transfer function of this circuit can be written as

$$T(s)_{LP} = \frac{I_{LP}}{I_{in}} = \frac{-\dfrac{g_m}{C_1C_2R_x}}{s^2 + s\dfrac{1}{C_1R_x} + \dfrac{g_m}{C_1C_2R_x}}. \tag{8}$$

From Eq. (8), the parameters a, b and c can be expressed as

$$a = c = \frac{g_m}{C_1C_2R_x}, \tag{9}$$

and $$b = \frac{1}{C_1R_x}. \tag{10}$$

Fig. 4(b) shows the lossless integrator using OTA. Considering the circuit in Fig. 4(b) and using OTA properties, we will receive

$$\frac{I_O}{I_{in}} = \frac{k}{s}, \text{ where } k=g_{mO}/C_3. \tag{11}$$

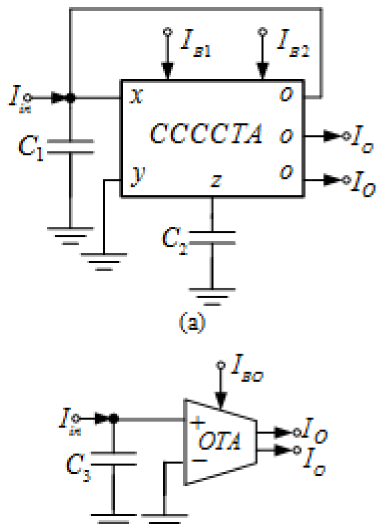

Figure 4. (a) 2nd order LP filter (b) integrator

The completed 3rd current-mode quadrature oscillator is shown in Fig. 5. The oscillation condition (OC) and oscillation frequency (ω_{osc}) can be written as

$$\text{OC: } \frac{1}{C_1 R_x} = \frac{g_{mO}}{C_3}, \tag{12}$$

and
$$\omega_{osc} = \sqrt{\frac{g_m}{C_1 C_2 R_x}}. \tag{13}$$

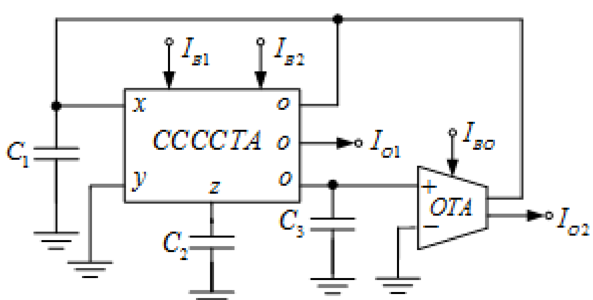

Figure 5. Proposed current-mode qudrature oscillator

If $R_x = V_T / 2I_B$, $g_m = I_{B2} / 2V_T$, $g_{mO} = I_{BO} / 2V_T$ and $C_1 = C_2 = C_3 = C$, the oscillation condition and oscillation frequency can be rewritten as

$$\text{OC: } 4I_{B1} = I_{BO}, \tag{14}$$

and
$$\omega_{osc} = \frac{1}{V_T C}\sqrt{I_{B1} I_{B2}}. \tag{15}$$

It is obviously found that, from Eqs. (14) and (15), the oscillation condition and oscillation frequency can be adjusted independently, which are the oscillation condition can be controlled by setting I_{B1} and I_{BO}, while the oscillation frequency can be tuned by setting I_{B2}. From the circuit in Fig. 5, the current transfer function from I_{o1} to I_{o2} is

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{g_{mO}}{sC_3}, \tag{16}$$

For sinusoidal steady state, Eq. (15) becomes

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = \frac{g_{mO}}{\omega_{osc} C_3} e^{-j90^\circ}. \tag{17}$$

The phase difference ϕ between I_{o1} and I_{o2} is ϕ= -90° ensuring that the currents I_{o2} and I_{o1} are in quadrature.

III. Simulation Results

To prove the performances of the proposed quadrature oscillator, the PSpice simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [20]. Internal construction of CCCCTA and OTA used in simulation are shown in Fig. 6(a) and (b).

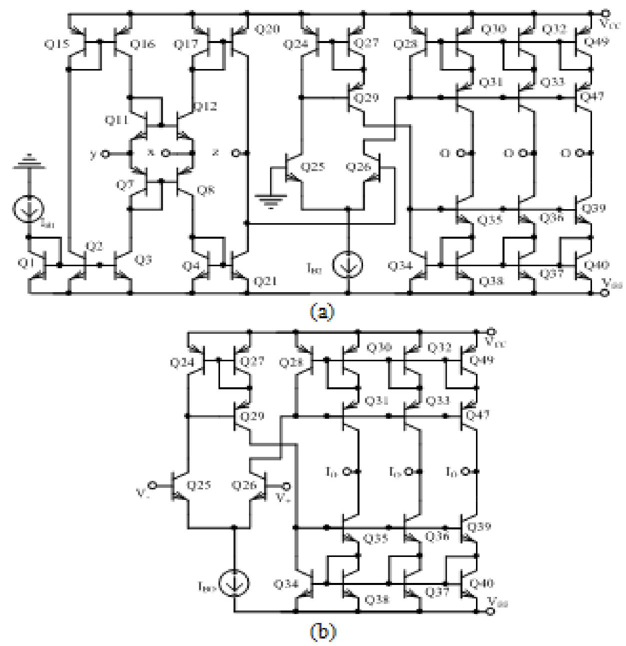

Figure 6. Internal constructions of (a) CCCCTA (b) OTA

The circuit was biased with ±2V supply voltages, C_1=C_2=C_3=0.5nF, I_{B1}=50µA, I_{B2}=200µA and I_{BO}=195µA. This yields oscillation frequency of 1.102MHz, where the calculated value of this parameter from Eq. (15) yields 1.22MHz (deviated by 16.39%). The power consumption of the circuit is 5.12mW. Figs. 7 and 8 show simulated quadrature output waveforms. Fig. 9 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 1.09%.

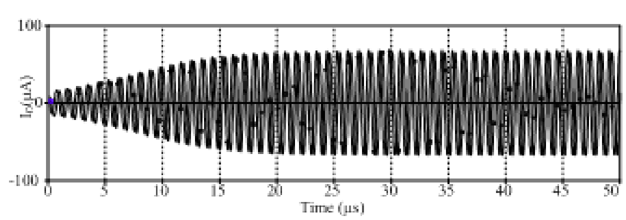

Figure 7. The simulation result of output waveforms during initial state

DOI: 01.IJEPE.02.03.21

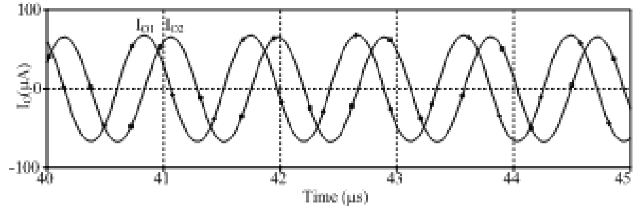

Figure 8. The simulation result of quadrature outputs

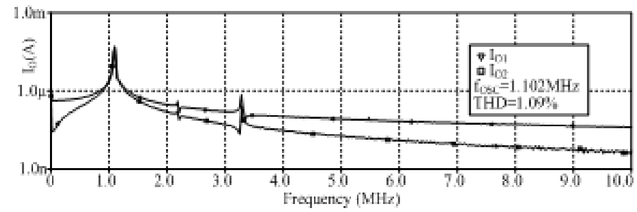

Figure 9. The simulation result of output spectrum

Conclusions

An electronically tunable current-mode quadrature oscillator based on CCCCTA and OTA has been presented. The features of the proposed circuit are that: oscillation frequency and oscillation condition can be electronically/independently tuned; the proposed oscillator consists of 1 CCCCTA, 1 OTA and 2 grounded capacitors, non-interactive current control of the condition of oscillation and frequency of oscillation and availability of quadrature explicit-current-outputs from high-output impedance terminals. PSpice simulation results agree well with the theoretical anticipation.

References

[1] I. A. Khan and S. Khawaja, "An integrable gm-C quadrature oscillator," *Int. J. Electronics*, vol. 87, no. 1, pp.1353-1357, 2000.

[2] C. Toumazou, F.J. Lidgey and D.G. Haigh, *Analogue IC design: the current-mode approach*, Peter Peregrinus, London, 1990.

[3] R. Prokop, V. Musil, "New modern circuit block CCTA and some its applications," *The Fourteenth International Scientific and Applied Science Conference - Electronics ET'2005*, Book 5. Sofia: TU Sofia, pp. 93-98, 2005.

[4] M. Siripruchyanun and W. Jaikla, "Current controlled current conveyor transconductance amplifier (CCCCTA): a building block for analog signal processing," *Electrical Engineering*, vol. 90, pp. 443–453, 2008.

[5] M. T. Abuelma'atti and H. A. Al-Zaher, "Current-mode sinusoidal oscillators Using Single FTFN," *IEEE Trans. Circuits and Systems-II: Analog and Digital Signal Proc*., vol. 46, pp. 69-74, 1999.

[6] U. Cam, A. Toker, O. Cicekoglu, and H. Kuntman, "Current-mode high output impedance sinusoidal oscillator configuration employing single FTFN," *Analog Integrated Circuits and Signal Proc*., vol. 24, pp. 231-238, 2000.

[7] S. S. Gupta and R. Senani, "Realisation of current-mode SRCOs using all grounded passive elements," *Frequenz,* vol. 57, pp. 26-37, 2003.

[8] M. T. Abuelma'atti and A.A. Al-Ghumaiz, "Novel CCI-based single-element-controlled oscillators employing grounded resistors and capacitors," *IEEE Trans. on Circuits and Systems-I: Fundamental Theory and Applications*, vol. 43, pp. 153-155, 1996.

[9] M. Bhusan and R.W. Newcomb, "Grounding of capacitors in integrated circuits," *Electronic Letters*, vol. 3, pp. 148-149, 1967.

[10] S. Minaei and O. Cicekoglu, "New current-mode integrator, all-pass section and quadrature oscillator using only active elements," *1st IEEE Int'l Conf. Circuits and Systems for Communications*, vol. 26-28, pp.70–73, 2002.

[11] K. Kumwachara and W. Surakampontorn, "An integrable temperature-insensitive gm–RC quadrature oscillator," *Int. J. Electronics*, vol. 90, no. 1, pp.599-605, 2003.

[12] J. J. Chen, C.C. Chen, H.W. Tsao, and S.I. Liu, "Current-mode oscillators using single current follower," *Electronics Letters*, vol. 27, pp. 2056-2059, 1991.

[13] M.T. Abuelma'atti, "Grounded capacitor current-mode oscillator using single current follower," *IEEE Trans. Circuits and Systems-I: Fundamental Theory and Applications,* vol. 39, pp. 1018-1020, 1992.

[14] J. W. Horng, "Current-mode quadrature oscillator with grounded capacitors and resistors using two DVCCs," *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, vol. E86-A, pp. 2152-2154, 2003.

[15] W. Jaikla and M. Siripruchyanan, "A Versatile quadrature oscillator and universal biquad filter using CCCDBAs," *Proceedings of ECTI con 2006*, Ubon-ratchathani, Thailand, pp.501-504, May 2006.

[16] W. Jaikla and M. Siripruchyanun, "A versatile quadrature oscillator and universal biquad filter using dual-output current controlled current differencing transconductance amplifier," *Proceedings of ISCIT 2006*, Bangkok, Thailand, pp. 1072-1075, 2006.

[17] W. Jaikla and M. Siripruchyanun, "CCCDTAs-based versatile quadrature oscillator and universal biquad filter," *The Proceedings of ECTI con 2007*, Chieng Rai, Thailand, pp. 1065-1068, 2007.

[18] J. W. Horng, C. L. Hou, C. M. Chang, H. P. Chou, C. T. Lin and Y. H. Wen, "Quadrature oscillators with grounded capacitors and resistors using FDCCIIs," *ETRI Journal*, vol. 28, pp. 486-494, 2006.

[19] P. Prommee, K. Dejhan, "An integrable electronic-controlled quadrature sinusoidal oscillator using CMOS operational transconductance amplifier," *International Journal of Electronics*, vol. 89, pp. 365-379, 2002.

[20] D. R. Frey "Log-domain filtering: an approach to current-mode filtering," *IEE Proc. Cir. Dev. Syst*., vol. 140. pp. 406-416, 1993.

DOI: 01.IJEPE.02.03.21